

Evaluating Vehicle Fire Training Inhalation Hazards

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THE NATIONAL INSTITUTE FOR OCCUPATIONAL Safety and Health (NIOSH) received a health hazard evaluation (HHE) request from an Ohio township fire and rescue department concerning potential inhalation exposures during vehicle fire suppression training [see sidebar “The Health Hazard Evaluation (HHE) Program”]. Although vehicle fires can be suppressed quickly, they can release hundreds of toxic chemicals into the air, which could cause short- and even long-term health effects over a firefighter’s career. Even after a fire is extinguished, the off-gassing of potentially harmful chemicals and particles may continue because of thermal decomposition. Some of the chemicals released from vehicle fires are likely to be different from those released during structural fires because vehicles contain materials such as rubber (belts, tires), petrochemicals (oil, gasoline), and acids (batteries).

Despite the known health hazards, it is still common for some firefighters not to wear self-contained breathing apparatus (SCBA) while fighting vehicle fires. One analysis found that firefighters in Montreal wore SCBA approximately 50 percent of the time at structural fires but only six percent of the time at all fires (which included vehicle fires).¹ Some firefighters may think their inhalation exposures to hazardous chemi-

icals and particles are minimal at vehicle fires because these fires tend to be suppressed within minutes and because they are not enclosed in a building. Furthermore, wearing an SCBA takes time and is cumbersome; some firefighters may think they should save breathing air for more intense fires. However, firefighters who do not wear SCBA while fighting vehicle fires could be overexposed to acutely toxic chemicals.

The fire department we evaluated conducts vehicle fire suppression training two to three times per year. Of its nearly 400 total runs per year, fewer than four percent of the fire responses are vehicle fires (this is below the national rate of 20 percent).² We conducted our evaluations during two training exercises. It is important to note that shock absorbers in the bumper present an explosion hazard to firefighters who attack fires from the front of the engine compartment. National Fire Protection Association (NFPA) 1403, *Standard on Live Fire Training Evolutions*, recommends removing shock absorbers before vehicle fire training.³ Similarly, struts used to assist in lifting hoods and trunk lids must be removed, or they can become missiles when exposed to fire.

During both evaluations, vehicle engines and cabins were separately set on fire. The firefighters waited two to five minutes to let the fires build before knocking down with water. Photo 1 shows the knockdown phase of the vehicle fire suppression training; knockdown took between one and three minutes and was followed by one to four minutes of overhaul (photo 2). The intensity of exposures to chemical vapors from



Photos courtesy of NIOSH.





vehicle fires depends on wind speed and direction. In both of our evaluations, the firefighters attacked the fires from locations in which the wind would be blowing away from them (upwind). This helps to minimize exposures and maximizes the firefighters' field of vision. Nevertheless, we observed instances when the firefighters encountered the smoke plumes because the winds shifted or because they changed positions to gain better access to the fires. Below, we discuss our two evaluations, describe the potential chemical and particle exposures during vehicle fire suppression, and identify controls and work practices that can reduce firefighters' exposures.

EVALUATION 1

Our first evaluation involved one vehicle and attempted to identify the main chemicals present in vehicle fire smoke.

The Health Hazard Evaluation (HHE) Program

Based on a federal law, NIOSH conducts health hazard evaluations (HHEs) to investigate possible workplace health hazards. Employees, employers, or union representatives can ask our comprehensive team of experts to investigate their health and safety concerns by requesting an HHE. Our team contacts the requestor and discusses the problems and how to solve them. This may result in sending the requestor information, referring him to a more appropriate agency, or making a site visit (which may include environmental sampling and medical testing). If we make a site visit, the end result is a report of our investigations that includes recommendations that are specific to the problems found, as well as general guidance for following good occupational health practices. These HHE reports are available on the Internet (<http://www.cdc.gov/niosh/hhe/>).

The engine and cabin of a 1991 Dodge Dynasty sedan were set on fire. Most of the belts and the battery were missing, and the gas tank had been emptied. The cabin interior was relatively unaltered. We collected area air samples of the smoke to identify the chemicals emitted in the vehicle fires. A firefighter in turnout gear and SCBA collected each area sample by holding the air-sampling canister in the smoke plume and opening the valve, which allowed the canister (which was under vacuum) to draw in one liter of smoke (photo 3). In addition, the four firefighters suppressing the fires wore air-sampling gear to measure volatile organic compounds and aromatic hydrocarbons in their personal breathing zone, which is the air in the general vicinity of the mouth and nose.

Results. We found high levels of various hazardous chemicals in the smoke (Table 1). However, the breathing zone concentrations we measured for naphthalene, acrylonitrile, styrene, benzene, and toluene were below short-term exposure limits (STELs). These results helped us determine what chemicals to sample for on our second evaluation. Because ve-

Table 1. Components of Vehicle Fire Smoke

Concentrations (in mg/m³) of 10 selected volatile organic compounds in the vehicle fire smoke (Evaluation 1)

| Select compounds | Engine fire | | | Cabin fire | | |
|---------------------|-------------|-----------|----------|------------|-----------|----------|
| | Start-up | Knockdown | Overhaul | Start-up | Knockdown | Overhaul |
| Benzene | 5.2 | 1.6 | 11 | 60 | 1.4 | 0.38 |
| 1,3-Butadiene | 2.3 | 0.40 | 4.8 | 6.8 | 0.25 | 0.05 |
| Toluene | 1.4 | 9.3 | 3.8 | 10 | 4.6 | 0.95 |
| Naphthalene | 1.4 | 0.93 | 1.2 | 10 | 0.60 | 0.17 |
| Styrene | 0.83 | 3.3 | 1.6 | 14 | 2.3 | 0.45 |
| Acrolein | 0.56 | 0.35 | 1.4 | 15 | 0.18 | 0.05 |
| Methyl methacrylate | 0.44 | 0.17 | 0.21 | 0.33 | 0.81 | 0.06 |
| Acrylonitrile | 0.32 | 0 | 0.77 | 27 | 0.38 | 0.07 |
| Acetonitrile | 0.28 | 0.12 | 0.70 | 14 | 0.12 | 0.03 |
| Ethyl benzene | 0.15 | 2.2 | 0.41 | 1.4 | 0.7 | 0.12 |

Source: NIOSH

hicle fires are suppressed quickly and exposures are generally less than 15 minutes in duration, we compared the breathing zone concentrations to STELs or ceiling limits. Some chemical substances have recommended STELs or ceiling limits to protect against health effects that could occur when a worker is exposed to them for a short time. Unless otherwise noted, the STEL is a 15-minute time-weighted average exposure that

should not be exceeded at any time during a workday, and the ceiling limit is an exposure that should not be exceeded at any time.

EVALUATION 2

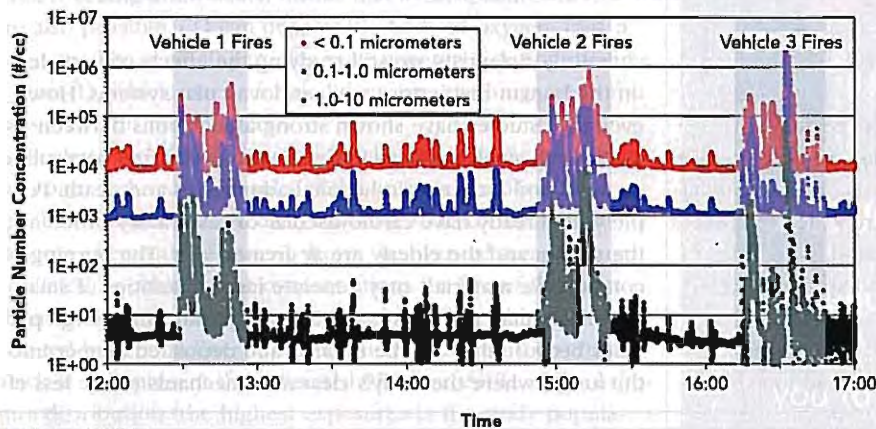
During our second evaluation, we measured the firefighters' personal exposures to chemicals and particles during the engine and cabin fires for three vehicles: a 1994 Ford Aerostar minivan, a 1986 Toyota Corolla sedan, and a 1986 Toyota Celica coupe. The belts, fluids, batteries, cushions, and upholstery were present in each vehicle, but the gas tanks had been emptied. Five firefighters were involved in suppressing the vehicle fires or assisting with sampling: a nozzle operator, a backup firefighter, an officer, a pump operator, and a duct holder (who held the flexible aluminum ducting that was used for particle sampling). The officer or backup firefighter performed forcible entry. Different firefighters were involved with each vehicle burn, but the same firefighter operated the pump for all fires.

Based on the results of our first evaluation and an extensive literature review, we decided to conduct breathing zone air sampling for specific aromatic hydrocarbons, aldehydes, and carbon monoxide (CO) (common by-products of organic material combustion), as well as isocyanates. Isocyanates are used in the manufacture of polyurethane materials, such as the polyurethane foam used in vehicle seat cushions. We also sampled for specific aromatic hydrocarbons, aldehydes, and isocyanates near the vehicle fires (area air samples). Last, we sampled for particles produced during the fires to determine their size and concentration. The possible health effects from exposure to these chemicals are briefly explained below.

Aromatic hydrocarbons. These include such chemicals as toluene, naphthalene, styrene, xylene, and benzene. Short-term exposures to some of these chemicals can irritate the eyes, the skin, and the respiratory tract; can cause the breakdown of blood cells; and can have effects on the central nervous system in the brain and the spinal cord. Long-term or repeated exposures to some of these chemicals can result in effects on the central nervous system, increased hearing damage when exposed

Figure 1. Particle Concentrations by Size (Evaluation 2)

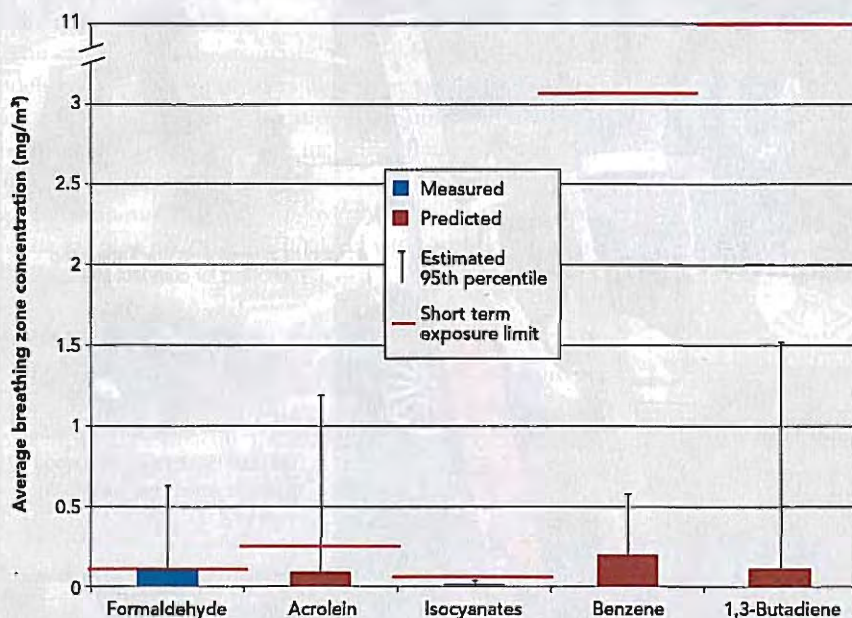
Particle concentrations for different particle size ranges (< 0.1 micrometers, 0.1 to 1.0 micrometer, and 1.0 to 10 micrometers diameter) throughout the day during the second evaluation. Cabin fires shortly followed engine fires for each vehicle.



Source: NIOSH

Figure 2. Breathing Zone Concentrations of Five Organic Chemicals

Average measured or predicted breathing zone concentrations of five organic chemicals measured during vehicle fire suppression.



Source: NIOSH

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to noise, reproductive or development problems, chronic hemolytic anemia (not enough red blood cells in the blood), cataracts, destruction of the protective fat in the skin, effects on bone marrow and the immune system, and development of cancers such as leukemia.

Aldehydes. These chemicals include formaldehyde and acrolein. Short-term exposures to these chemicals can cause severe eye, skin, and respiratory tract irritation and possible

ation in which tissues are starved of oxygen and, potentially, a person may become unconscious and stop breathing. Additionally, the person has an increased risk for heart problems. Long-term or repeated exposures can affect the cardiovascular system and central nervous system and possibly cause problems with human reproduction or development.

Particles. Particles or particulates are airborne solids or liquids that may or may not be associated with specific toxic

If the firefighters had not worn SCBAs, some of them would have been overexposed to formaldehyde, a known cause of cancer.

pulmonary edema (fluid buildup in the lungs); long-term or repeated exposures can cause cancer.

Isocyanates. Short-term exposures to isocyanates can cause eye, skin, and respiratory tract irritation and can lead to asthma-like reactions, bronchitis, pneumonitis (lung inflammation), and pulmonary edema. Long-term or repeated exposures can cause asthma-like symptoms such as cough, wheezing, chest tightness, and/or breathlessness when exposed to the chemical.

Carbon monoxide (CO). Short-term exposures to CO may decrease oxygen levels in the blood. This can lead to asphyxi-

chemicals. Scientists are still studying the effects of particles on the human respiratory and cardiovascular systems. However, past studies have shown strong associations between elevations in small particles in the air ("ambient fine particulate matter") and increases in hospital admissions and death. People who already have cardiovascular or respiratory problems, the young, and the elderly are at greatest risk. The burning of combustible materials may generate large quantities of small particles. Small particles may be more harmful than large particles because they can be inhaled and deposited deeper into the lungs, where the body's clearance mechanisms are less ef-

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fective, potentially causing more harmful health effects. Larger particles are often trapped and cleared by the body's natural defense mechanisms (for example, the mucous lining in the upper respiratory tract).

Results. Two of the 15 breathing zone concentrations of formaldehyde were above the NIOSH ceiling limit. If the firefighters had not worn SCBAs, some of them would have been overexposed to formaldehyde, a known cause of cancer and a respiratory sensitizer. Isocyanate concentrations were just below the STEL during the vehicle cabin fires. However, one sample collected near the vehicle fires measured isocyanates above the STEL, so overexposures to isocyanates could occur during vehicle cabin fire suppression. Isocyanates are also respiratory sensitizers. One CO concentration was just below the NIOSH ceiling limit, which means that overexposures to CO are also possible. CO can deprive the body of oxygen. Last, a large number of small particles were generated during the fires (Figure 1), which can be inhaled deep into the lungs and can cause harmful health effects.

Because we did not measure all chemicals in the breathing zone, we used the results of the area air sampling from the first evaluation to predict breathing zone concentrations of some chemicals.⁴ Figure 2 shows the average measured or predicted breathing zone concentrations for five of the most abundant or hazardous organic chemicals emitted in the fires. The red horizontal lines represent the STELs, and the vertical black lines represent the estimated 95th percentile of the exposure distribution (the highest exposures in the study population). On an additive basis, the mixture of highest exposures in the study population was nearly 10 times the acceptable level. (4) The most likely symptoms that could result from these exposures are irritation to the respiratory tract and eyes. Many of these compounds are also known human carcinogens (formaldehyde and benzene) or probable human carcinogens (1,3-butadiene). Being exposed to carcinogens does not necessarily mean a person will develop cancer later in life, but exposures to carcinogens should be minimized as much as possible.

The cars used in the exercises were older models. Newer models contain more polymers and other synthetic materials that can release high concentrations of a number of hazardous compounds when burned, including hydrogen cyanide, hydrogen sulfide, hydrogen chloride, and other inorganic and organic compounds. Therefore, overexposures to these compounds are also possible, particularly when suppressing fires from newer vehicles.

RECOMMENDATIONS

Although we did not measure the firefighters' exposures to all possible chemical hazards, we demonstrated the potential for overexposure to acute toxicants. We recommended the actions listed below to this fire department to protect firefighters from adverse health effects. We encouraged this department to use a labor-management health and safety committee or working group to discuss our recommendations and to develop an action plan. The following recommendations can be applied to any fire department:

- Use SCBA when responding to vehicle fires. Don SCBA

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When arriving at the fire scene and doff SCBA only after overhaul is complete. Make this protocol written policy.

- Position the pump operator and fire apparatus upwind of the vehicle fires to minimize exposures to the vehicle fire emissions (since the pump operator does not usually wear an SCBA).
- Position the pump operator and other crew in an area upwind of diesel exhaust from the fire apparatus (because diesel exhaust also contains hazardous substances).
- Encourage firefighters to talk to the chief about any health and safety concerns.
- Follow NFPA 1403 when conducting vehicle fire training exercises.

ENDNOTES

1. Austin CC, Dussault G, Ecobichon DJ. (2001). Municipal firefighter exposure groups, time spent at fires and use of self-contained-breathing-apparatus. *Am J Ind Med*; 40:683-692.
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4. Fent KW, Evans DE. (2011). Assessing the risk to firefighters from chemical vapors and gases during vehicle fire suppression. *J Environ Monit*; 13(3):536-543.

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